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Use of Doppler LIDAR for measuring the vertical profiles of wind speed at a coastal site

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ABSTRACT

LIDAR (LIght Detection And Ranging) technology has been increasingly used in ground-based remote sensing applied to atmospheric studies. The progressive increase in height of wind turbines, which demand expensive high meteorological towers, has prompted the improvement of the design of remote sensing devices suitable for estimating vertical profiles of wind speed and direction in the lower part of the Atmospheric Boundary Layer (ABL). Doppler LIDARs, are now increasingly used operatively for this purpose reaching suitable heights of use in developing large wind parks. Most studies on the reliability of Doppler LIDAR have been performed over homogeneous terrain or offshore where the columnar distribution of aerosols is generally homogeneous. Here, we address the use of a Doppler LIDAR in coastal areas, presenting results from an experiment carried out at a coastal site (600 m from the coastline) in the Central Mediterranean during a July 2009 using a WLS7 Windcube LIDAR. Moreover, a CL31,Vaisala ceilometer has been used to measure the vertical concentrations of aerosols. Turbulence measurements were available at the surface to estimate stability conditions and SODAR (SOnic Detection And Ranging) (DSDPA.90-24-METEK) has been used for comparing wind profiles with the LIDAR. In a companion contribution, in this conference, Lo Feudo et al. describe the evolution of the vertical structure of the coastal boundary layer during sea breeze in different atmospheric conditions. Here, we focus on the Doppler LIDAR performance. During nighttime, stable conditions developed under a light land breeze and the LIDAR signal could reach 250 m, often detecting a low level jet confirmed by the SODAR measurements. During daytime, we identify two atmospheric regimes: during stationary westerly synoptic winds the LIDAR signal reached the maximum measurement height; during sea breeze conditions, at the onset of the breeze, the Doppler LIDAR vertical wind profile rarely reached higher than 180 m. We believe that the sea breeze advection of marine aerosols causes a non homogeneous columnar distribution inducing a low LIDAR signal-to-noise ratio above the internal boundary layer. Comparisons with the ceilometer and SODAR measurements seems to confirm this hypothesis.

1. INTRODUCTION

Processes in the Atmospheric Boundary Layer (ABL) are not only confined in a specific layer or time scale but also interact [1] [2]; therefore, beside point measurements at fixed height above the ground, there is the need to investigate the development of the vertical structure of atmospheric parameters such as wind speed, U and scalars such as temperature T, humidity Q and turbulent fluxes. LIDAR and SODAR technologies have been shown to be of use to study the vertical structure of the atmospheric boundary layer and studies have mostly been conducted on land or offshore. [3] [4] [5] [6] In this context, coastal areas are particularly challenging environments due to the sharp discontinuity in the surface properties that demands high resolution models to resolve flows induced by the coastal discontinuity; moreover, since advection is a predominant component of the flow, it is important to study the limit of the applicability of the remote sensing devices based on the principle that the vertical structure of the ABL with respect to aerosol concentration does not change in time and space.

Also uncertainties in numerical simulations of the atmospheric flow rely on the accurate sub-grid parameterization in models and therefore on the understanding of the atmospheric processes at the time and space scale of interest.

Therefore, there is a need for intensive campaigns to provide complete datasets spanning the entire vertical extension of the atmosphere to both parameterize and test model performances for any application.

We present a study of the experimental development of the coastal flow at a site located 600 m from the coastline in the Central Mediterranean area [7] [8] using surface turbulent data and datasets from ground-based remote sensing devices based on different measuring principles addressing the performance of a pulse Doppler LIDAR (Windcube) compared to a SODAR, and using a ceilometer to measure the vertical structure of the ABL with respect to the content of aerosols.

2. EXPERIMENTAL SET UP

An intensive experimental campaign was organized during the period 03 July 2010 and 4 august 2010 at a coastal site located 600 m from the coastline. (Figure1). The following remote sensing instruments were installed: a LIDAR (WLS7 Windcube), a ceilometer (CL31, Vaisala) and a SODAR (DSDPA.90-24-METEK). At the surface, mean and turbulent meteorological parameters where sampled by standard meteorological instruments and by a METEK Ultrasonic anemometer respectively at the height of 10 m.

2.1 The LIDAR (WLS7 Windcube, LEOSPHERE)

The Windcube is pulsed Doppler LIDAR wind profiler operating at the eye-safe 1.5μm wavelength. It has a 30° prism to deflect the beam from the vertical.

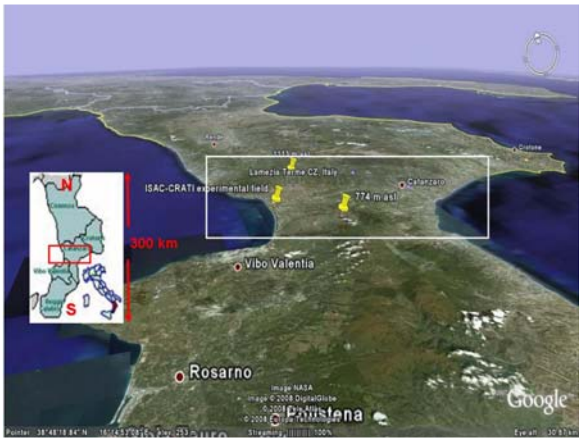

Figure 1. Geographical location of the site.

The LIDAR sends a stream of pulses (5000-10000) in a given direction, recording the backscatter in a number of range gates (fixed time delays) triggered by the end of each pulse. The averaged Doppler spectrum obtained for each pulse-stream gives a radial wind speed, i.e. the projection of the wind speed along the line-of-sight. The Windcube lidar measures the radial speed in 4 directions azimuthally separated by 90 degrees, see figure 2. The full 3-D wind speed vector is retrieved by combining the four last consecutive radial speeds.

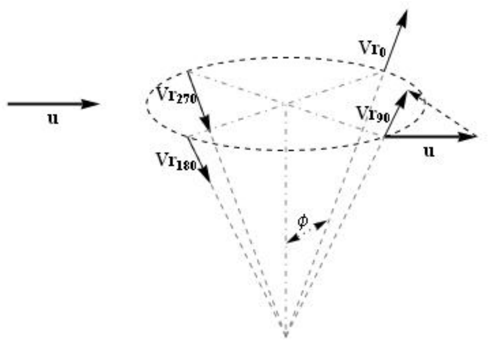

Figure 2. Windcube lidar scanning

The maximum measuring height of the instrument was set to 250 m. At each measuring height, the diameter of the rotation is almost comparable to the height. In this frame, especially at the upper level, in presence of advection of air with different aerosol size distribution, the instruments might receive backscatter from air parcels with different speed and aerosol concentration. A ceilometer was used to monitor the vertical column of aerosol. [9]

2.2 The ceilometer (Vaisala CL31)

Ceilometers incorporate diode laser based LIDAR technology, which allows an active range-resolved optical remote sensing measuring technique. A ceilometer transmits laser pulses vertically and measures the backscattered signal that depends on the amount of scattering particles in a volume at a certain distance from the instrument. It uses infrared light of 910 nm, has a height resolution of 20 m, and a maximum range of 7500 m and data are collected at a frequency of 1s. In [10] Lo Feudo et al. (this proceeding), discussed the performance of the CL31, which brought to choose an average of the signal of 5 minutes.

2.3 The SODAR (DSDPA.90-24-METEK)

The SODAR is an acoustic sounder and provide wind and turbulence vertical profiles, It operates ranging from 45m to 405 m height with a working frequency of 1280 Hz. Sampled data are averaged every 10 minutes. Acoustic signals are back scattered by the acoustic refractivity index.

2.4 Atmospheric conditions

In figure 3, we show the meteorological conditions during the campaign.

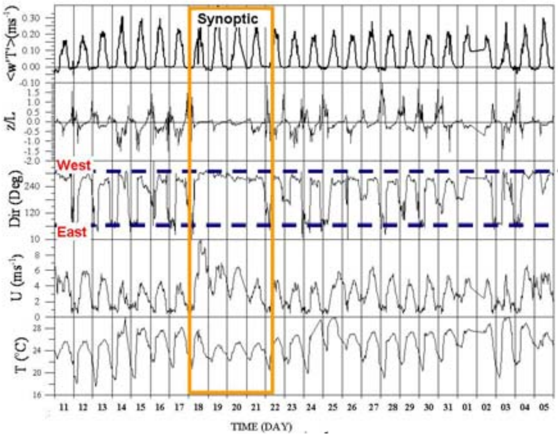

Figure 3. From top to bottom, time series of turbulent heat flux <w'T'> (note that positive values indicate upward fluxes), the Monin-Obukov z/L , wind direction DIR, wind speed U, air temperature T, the area in the orange box corresponds to synoptic flows; dashed line delimits the cycle of the complete sea/land breeze in West-East directions.

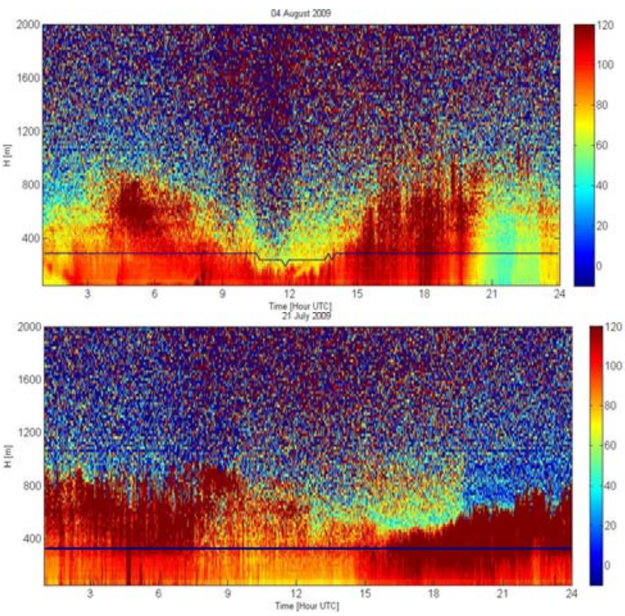

Figure 4. Combined Windcube- Ceilometer plot. Daily evolution of the vertical structure of the ABL at the site in two different situations: 1) sea-breeze (top plot) and 2) synoptic flow (bottom plot). We note that advection of marine aerosols during sea breeze cases causes a variation of the vertical content of the aerosol likely due to the development of an internal boundary layer.

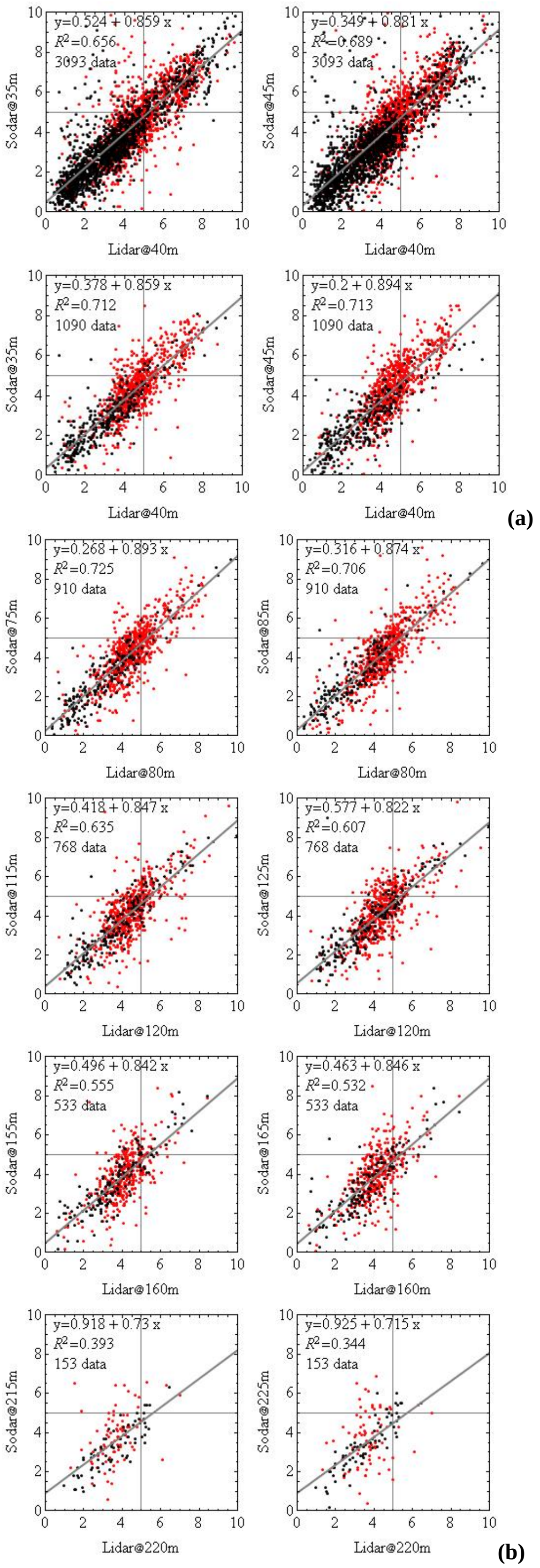

Figure 5. Comparison between wind speeds measured by the Windcube and the SODAR at different heights. Red dots correspond to daytime and black dots to nighttime. Note that the height of SODAR and LIDAR do not coincide, therefore, for each Windcube measurement height, we show the comparison with SODAR data both from the height below and from the height above.

3. RESULTS AND DISCUSSION

In this paper, we have addressed the performance of the Windcube LIDAR, at a coastal site, 600 m from the coastline, during an experiment performed in July/August 2009. Different ground-based remote sensing devices utilizing different physical principles were used.
In the considered area, both synoptic and sea breeze regimes result in westerly winds advecting marine aerosols inland. However, the effect of the advection of the aerosols on the structure of the inland coastal ABL is different in the two meteorological situations. A key instrument for understanding the performance of the LIDAR is the ceilometer that detects vertical discontinuity in aerosol concentration.

During daytime, the two regimes cause different performance of the Windcube:

- During stationary westerly synoptic winds the Windcube vertical wind profiles reach the maximum fixed height 250 m. We believe that marine aerosols, constantly advected from the sea during persistent synoptic flow with wind speed larger than 4 ms^{-1}, are mixed with land aerosols and are homogeneously distributed along the vertical air column. This is confirmed by the ceilometers that detects a discontinuity at a constant stationary height of about 800 m.
- During consecutive days of stationary sea-land breeze regime, after the onset of the sea breeze at around 10:00 UTC in Figure 4 (Top), the Windcube's maximum obtainable measuring height is often limited to 180 m. However, as the sea breeze intensity increases and become stationary around 14:00 UTC, the maximum height reached by the Windcube increases. The ceilometer signal shows a decrease of the height of the discontinuity in aerosol concentration before 11:00 UTC and an increase after 14:00. We suppose that the sea breeze advection of marine aerosols, confirmed also by the ceilometer signal, is the cause of the LIDAR low signal-to-noise ratio at high levels.
- During night time, the surface layer is stable and the land breeze is light, often contrasted by the synoptic westerly flow. The ground bases inversion at around 300-400 m, that develops in these conditions, traps the land-marine aerosols mixed in the late afternoon, and the LIDAR signal then successfully senses up to the top maximum level, i.e. 200 m, due to the homogeneous distribution of aerosols. A low level jet is often detected in agreement with the SODAR measurements.

We also compared the wind speeds measured by the LIDAR and the SODAR. Since the working principle of the latter is based on density fluctuations due to the thermal structure of the ABL, the SODAR signal during daytime is not disturbed by the aerosol advection. In Figure 5, we show the comparison of the wind speed from the two instruments. The top plots in Figure 5 (a) show the raw data at 40 m (lidar height) whereas the bottom plots show the data after filtering out the bad quality sodar and lidar data. About 2/3 of the data were removed. Figure 5 (b) shows the filtered data at other heights. We can see that the amount of data decreases at higher height. At high levels, i.e. above 180m, the two instruments are only correlated in cases where the LIDAR is not disturbed by the marine aerosols advection.

4. CONCLUDING REMARKS

In coastal areas the Windcube signal depends on the height of the mixed layer with respect to aerosol concentration. The maximum height at which measurements are possible with the pulsed lidar can be used to give an indication of the height of the well-mixed layer.

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